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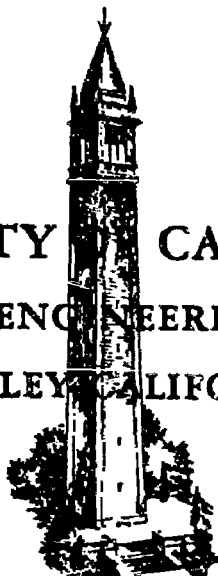
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THE EFFECT OF DISPERSIONS  
ON THE  
CREEP PROPERTIES  
OF  
ALUMINUM-COPPER ALLOYS

Twenty Second Technical Report

By

Warren H. Giedt, Oleg D. Sherby and John E. Dorn

22, N7-onr-295, Task Order II,  
SERIES NO. NR-031-048  
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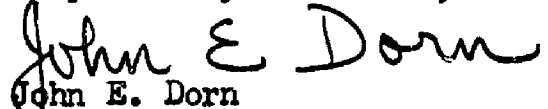
Attention: Dr. O. T. Marzke

Dear Sir:

Attached hereto is the Twenty Second Technical Report on Contract N7-onr-295, Task Order II, NR-031-048, entitled "The Effect of Dispersions on the Creep Properties of Aluminum-Copper Alloys".

The wholehearted cooperation of the Office of Naval Research in making these studies possible is sincerely appreciated.

Respectfully submitted,

  
John E. Dorn

Professor, Physical Metallurgy

JED:bp

THE EFFECT OF DISPERSIONS  
ON THE  
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By

Warren H. Gledt <sup>(1)</sup>, Oleg D. Sherby <sup>(2)</sup> and John E. Dorn <sup>(3)</sup>

Twenty Second Technical Report, Series 22, Issue 22, N7-onr-295,  
Task Order II, NR-031-048

December 1, 1952

(1) Assistant Professor of Mechanical Engineering, (2) Research Engineer  
and (3) Professor of Metallurgy, University of California, Berkeley,  
California

### ABSTRACT

The creep properties of Al-Cu alloys containing hard particles of  $\text{CuAl}_2$  are primarily dependent on the volumetric mean free path of the particles and independent of minor variations in composition and heat treatment. The creep stress was found to correlate with the creep rate-temperature parameter  $\dot{\epsilon} = \dot{\epsilon}_0 e^{\Delta H/RT}$ . Above  $\ln \dot{\epsilon} = \ln(\dot{\epsilon}_0 e^{\Delta H/RT}) = 46.0$  and below  $\ln \dot{\epsilon} = 27.5$  the finer dispersions are superior, whereas over the intervening range of  $\dot{\epsilon}$  values the coarser dispersions are superior.  $\Delta H$  was found to be a constant of about 37,000 calories per mole.

## INTRODUCTION

Although extensive investigations have already been conducted on biphasic alloys, no definitive conclusion has yet been reached on how the fineness of dispersions of intermetallic compounds in the alpha matrix affects their creep resistance. Several investigators (1,2) found that the coarser dispersions exhibit superior creep resistance; and this prevailing conclusion is consistent with the widely postulated thesis that the most stable structure induces the greatest creep resistance. But the generalization that coarser dispersions always provide greater creep resistance should not be made without qualifications. First, the differences in the pretreatments that are used to develop the various dispersions might also alter other less readily detected structural factors. For example, when the fine and coarse dispersions are produced by the crude procedure of chill casting and sand casting respectively, it cannot be clear whether the observed differences in creep behavior should be ascribed to the differences in the dispersion, differences in the grain sizes of the alpha solid solution matrix, differences in residual stresses, or even differences in the strain hardened state arising from plastic deformation resulting from thermal gradients that were introduced during cooling. Secondly, the creep properties at low temperatures and high strain rates parallel somewhat the tensile properties. In this range, therefore, the finer dispersions would be expected to exhibit superior creep resistance. And thirdly a few observations at relatively high temperatures have shown that the finer dispersions are superior in creep resistance to coarser dispersions.

It is possible that the present state of knowledge regarding the effect

of dispersions on creep is due to the fact that thus far only few tests have been made on isolated examples; no systematic study has yet been reported on the effects of dispersions on the creep resistance of biphase alloys. It was therefore, the intent of this investigation to attempt a systematic study on the effects of dispersions of  $\text{CuAl}_2$  on the creep behavior of high purity Al-Cu alloys.

#### MATERIALS AND TECHNIQUES

Alloys containing dispersions of  $\text{CuAl}_2$  in the alpha solid solution matrix of Al were selected for this investigation because adequate heat-treating techniques for making a series of dispersions had already been developed during studies on the effect of dispersions on the tensile properties of biphase alloys (3). Since the heat-treatments were reasonably similar for each of the dispersions, it was thought that the small differences in time and temperature of annealing that were required to produce the various dispersions might not be too serious a factor per se in masking the desired relationship between dispersion and creep resistance. The good correlations that were obtained between the tensile properties and dispersions suggested that these minor differences in heat treatment did not introduce significant auxiliary effects.

Since the details of the heat treatments have already been reported they will not be reproduced here (3). The chemical composition, grain size, and dispersion of the heat treated alloys are given in Table I. As shown in the second column of Table I, the grain size of the alpha solid solution matrix was held to about the same value for all dispersions with the exception of the 3% V.C. alloy. The volumetric free path,  $\lambda$ , between the  $\text{CuAl}_2$  particles in the alpha solid solution matrix, shown in the third column,



TABLE I

Chemical Composition, Grain Size and Volumetric Mean Free Path

Dispersion Designation	Grain Size in grains/mm.	$\lambda$ V.M.F.P. in cm.	Composition by Weight**				
			Chemical Analysis Cu	Spectro-Chemical Analyses			
				Si	Fe	Mn	Zn
3% M*	2.4	0.00096	3.05	0.002	0.002	trace	0.0004
3% C	2.3	0.00365					
3% V.C.	0.8	0.0097					
4% F	2.3	0.00078	4.03	0.002	0.002	0.001	0.0004
4% M	2.3	0.00155					
4% C	2.4	0.0064					
5% F	2.1	0.00062	5.05	0.003	0.002	0.002	0.0006
5% M	2.2	0.0047					
5% C	2.3	0.0069					

\* F = Fine; M = Medium; C = Coarse; V.C. = Very Coarse

\*\* Chemical analyses and alloys supplied by courtesy of the Aluminum Company of America Research Laboratories.

varied over a factor of 15 times among the various dispersions.

Constant load creep tests\* up to about six weeks duration were conducted over a range of temperatures from 350° to 578°K (170°F to 580°F). The experimental details recounting the precision of stressing, temperature control, and strain measurement have already been reported (4).

## RESULTS AND DISCUSSION

### A. Effect of Dispersions on the Creep Properties at 422°K.

The stress versus the secondary creep rate curves, shown in Figure 1, were selected to provide a facile comparison of the effect of dispersions on the creep resistance of Al-Cu alloys at 422°K. In each alloy the coarse dispersion (large values of  $\lambda$ ) exhibited the greatest creep resistance whereas the fine dispersion (small values of  $\lambda$ ) was least creep resistant.

The data shown in Figure 2 illustrate more clearly that the creep stress for a given secondary creep rate increases with the volumetric mean free path  $\lambda$  between the dispersed particles. This effect is most pronounced for the lowest secondary creep rate that is recorded. Some minor scatter was obtained in the data, suggesting that some unknown factor might yet be affecting the creep resistance. But the general consistency of the results implies strongly that the creep resistance of biphase alloys depends primarily on the mean free path between the dispersed particles and is independent of minor differences in the percentages of that phase and minor differences in heat treatment that are required to produce the different dispersions.

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\* The original data are reported in the graphs that are assembled in the appendix.

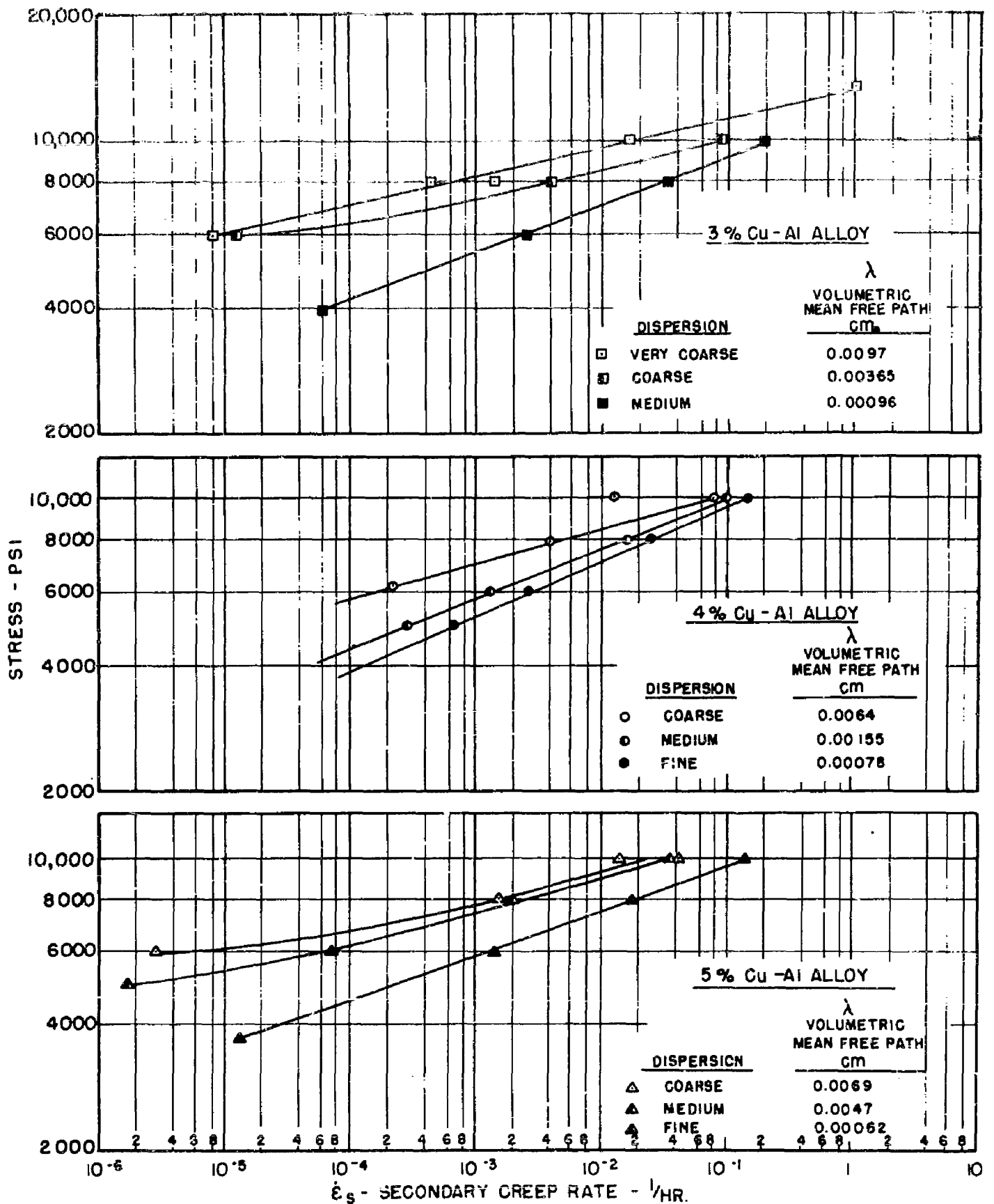


FIG. 1 THE CREEP PROPERTIES OF AL-Cu ALLOYS AT 422 °K.

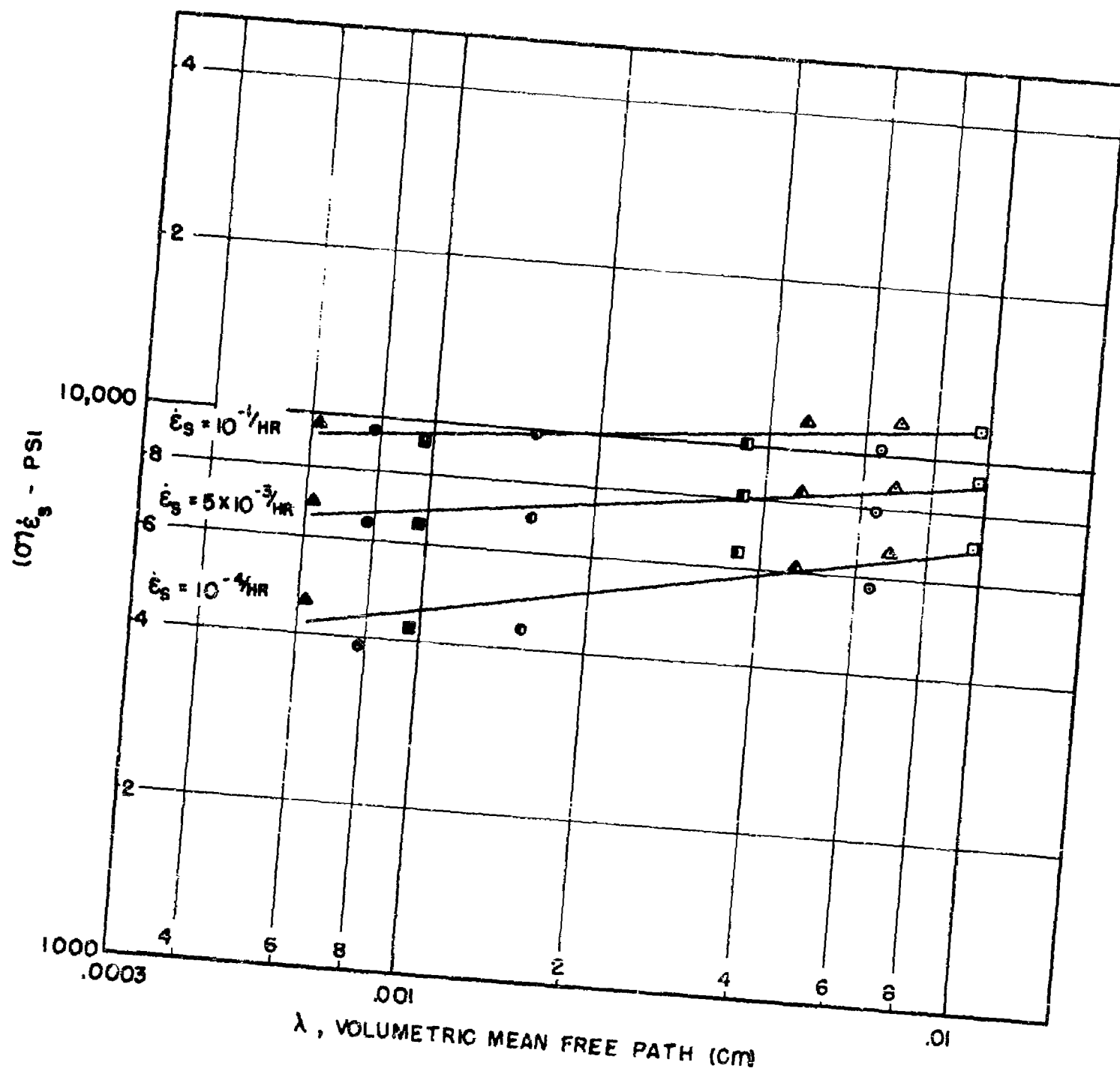


FIG. 2 EFFECT OF DISPERSIONS ON THE CREEP RESISTANCE OF Al - Cu ALLOYS AT 422°K.

## B. Effect of Temperature.

As shown in Figure 3 the high temperature tensile properties of these dispersion alloys, obtained from a previous report, (5) exhibit two inversions. Below about 450°K and above about 600°K the flow stress at a strain of ten percent is greater for the finer dispersion. Over the intermediate range from 450°K to 600°K the coarser dispersion exhibits the highest flow strength in tension. These results have been attributed to the effects of recovery on the properties. At the low temperatures where recovery is absent, the finer dispersions have higher tensile properties and at the higher temperatures where recovery is practically complete, the finer dispersions again exhibit the higher tensile properties. But, as shown by the less precipitous decrease in tensile properties of the coarser dispersion with temperature, over the range of temperatures where only partial recovery occurs, the coarser dispersion alloys recover more slowly than the finer dispersions, causing the inversions. If creep properties are also dependent upon somewhat the same factors of strain-hardening and recovery that are operative in determining the tensile properties, the same inversions might also be applicable to creep. In view of the lower strain rates in a creep test, however, the inversions might be expected to occur at lower temperatures than those recorded for the tension data. Furthermore for constant temperature creep tests the inversions will appear as a function of the secondary creep rates.

The data recorded in Figure 4 reveal that the suspected inversions in creep behavior do in fact occur. At 350°K and higher secondary rates the finer dispersion alloy exhibits higher values of creep stress, whereas at lower secondary creep rates the coarser dispersions are more creep resistant.

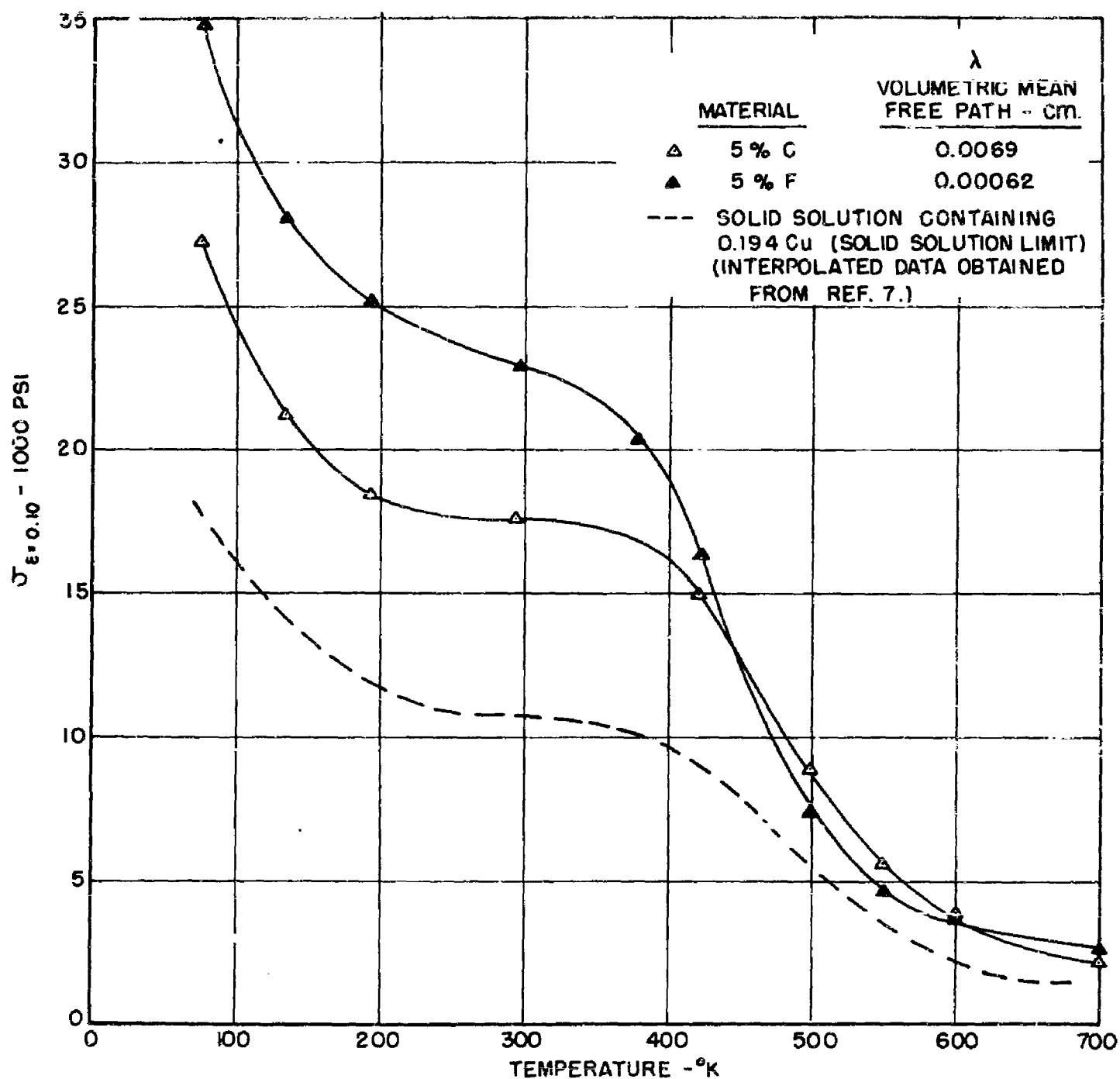


FIG. 3 EFFECT OF TEMPERATURE ON THE DEFORMATION STRENGTH OF A FINE AND COARSE Al-Cu DISPERSION ALLOY. (5)

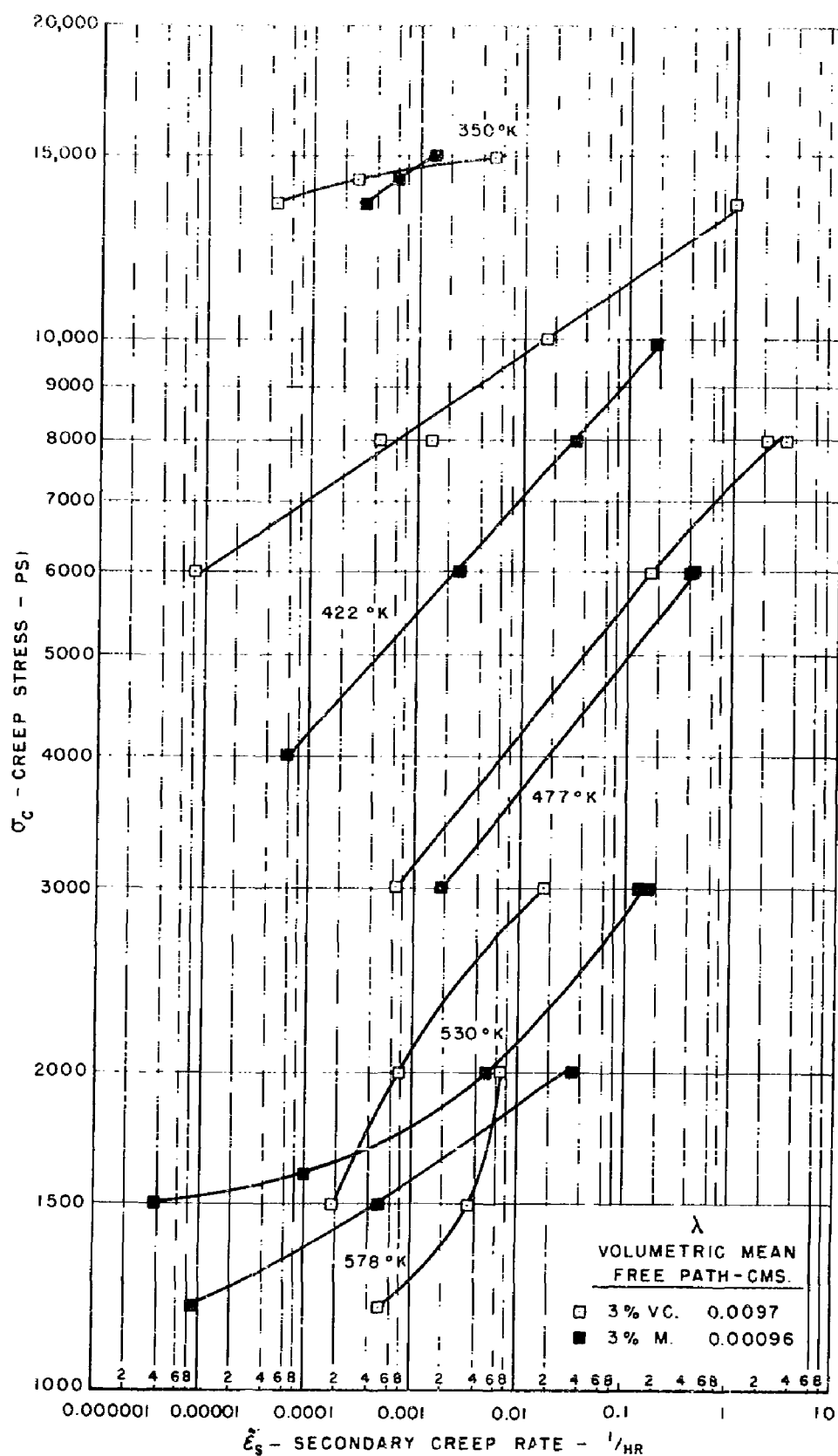


FIG. 4 EFFECT OF TEMPERATURE ON THE CREEP PROPERTIES OF A FINE AND COARSE Al-Cu DISPERSION ALLOY

At 530°K and  $\dot{\epsilon}_s = 3 \times 10^{-4}$  and at 578°K and  $\dot{\epsilon}_s = 3 \times 10^{-3}$  the second inversion occurs wherein the finer dispersion is again superior to the coarser dispersion for the lower secondary creep rates.

### C. Creep Rate-Temperature Relationships.

In previous investigations on the creep behavior of binary alpha solid solutions <sup>(7)</sup>, the creep strain for a constant load test was found to be a simple function of a temperature-compensated time according to which

$$\epsilon = f(\Theta, \sigma_c) \quad (1)$$

where

$\epsilon$  = total creep strain

$\sigma_c$  = initial stress in a constant load test

$\Theta = t e^{-\Delta H/RT}$  = temperature-compensated time

$T$  = absolute temperature during creep

$t$  = time under creep load

$\Delta H$  = activation energy

$R$  = gas constant

There is now substantial credence for the justification of Equation 1 because it has been recently shown <sup>(8)</sup> that the grain sub-structure and the tensile properties following constant load precreeping depend only on  $\Theta$ . Furthermore, upon differentiating with respect to time and evaluating the secondary creep rate,  $\dot{\epsilon}_s$ , the Zener-Holloman expression <sup>(9)</sup>

$$\sigma_c = F(\dot{\epsilon}_s e^{\Delta H/RT}) = F(Z) \quad (2)$$

is obtained, where  $\dot{\epsilon}_s$  is the secondary creep rate. This relationship was



found to be useful for correlating the creep behavior of binary alpha solid solutions (7). In addition, good correlations were also obtained between creep and tensile data where  $\sigma_c$  was taken as the ultimate tensile strength and  $\dot{\epsilon}_s$  as the strain rate in tension.

Assuming that the structures of dispersion alloys are also functions of the creep stress and the temperature-compensated time, Equation 2 should also apply to this class of alloys. Thus it is seen that inversions of properties should depend on the secondary creep rate and the test temperature in accord with the parameter  $(Z) = \dot{\epsilon}_s e^{\Delta H/RT}$ . Selecting, by appropriate means,  $\Delta H = 37,000$  calories per mole for the dispersion alloys gives the good correlations shown in Figure 5.

The dispersion alloy with  $\lambda = .00096$  cm agreed exceptionally well with the use of this relationship; the coarse dispersion with  $\lambda = .0097$  cm, on the other hand, did not correlate as well as in the intermediate ranges of  $\dot{\epsilon}_s e^{\Delta H/RT}$ . Nevertheless, it is felt that the use of the strain rate-temperature parameter  $\dot{\epsilon}_s e^{\Delta H/RT}$  is generally valid for the more complex biphasic alloys studied here. The activation energy for creep for the two dispersions placed under scrutiny was only slightly higher than the value of about 35,800 calories per mole that was previously found to be valid for dilute alpha solid solutions in aluminum. Below  $\ln Z = \ln(\dot{\epsilon}_s e^{\Delta H/RT}) = 27.5$  and above  $\ln Z = 46.0$  the finer dispersions exhibited superior creep resistance, whereas over the intermediate range of  $Z$  values the coarser dispersions were more creep resistant.

#### D. Effect of Dispersions on the Creep Properties.

Neglecting the small differences between the activation energies for

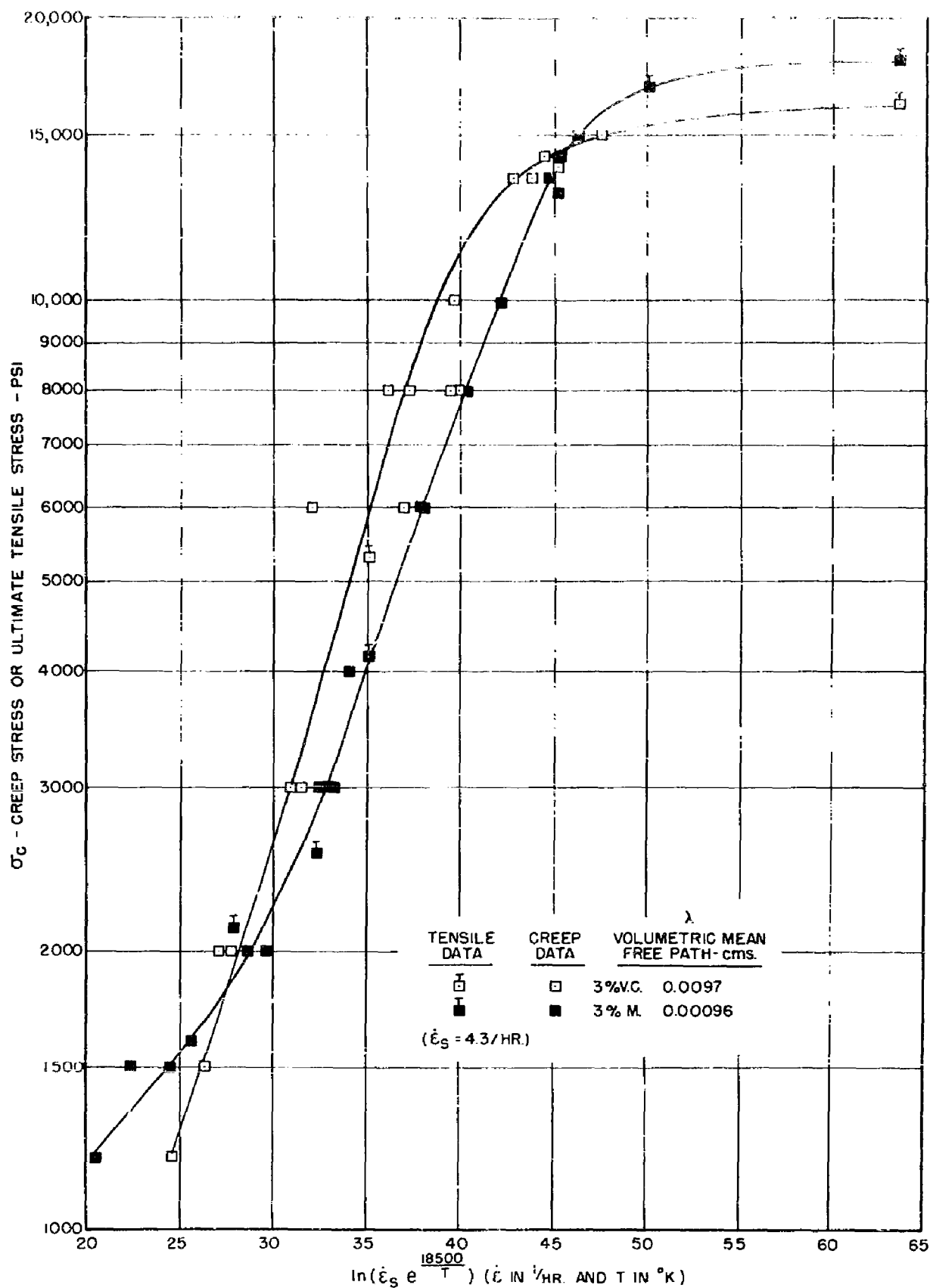


FIG. 5 CORRELATION OF CREEP DATA IN FIGURE 4 BY MEANS OF THE PARAMETER  $z = (\dot{\epsilon}_s e^{\frac{\Delta H_f}{RT}})$ .

dispersion alloys as contrasted to dilute alpha solid solutions, an evaluation of dispersions on the creep behavior of alloys as compared to solid solution alloying can be obtained by comparing their  $\dot{\epsilon}$  -  $\sigma$  curves as shown in Figure 6. The data clearly reveal that solid solution alloying with copper increases the creep resistance of aluminum. There is a further increase in the creep properties due to the presence of the dispersion of  $\text{CuAl}_2$  particles. The increase in creep resistance due to the intermetallic compound, however, is not as large as its effect on the low temperature tensile properties (see Figure 3).

#### E. Creep Strain as a Function of the Temperature-Compensated Time.

The general validity of Equation 2 for the dispersion alloys implies that Equation 1 should also be valid. The correlations between the creep strain and the temperature-compensated time are shown in Figure 7 and 8. Although these data uphold the nominal validity of Equation 1 there appears to be some scatter in the results. Although this scatter is greater than that previously obtained for alpha solid solutions, its origin was not uncovered.

### CONCLUSIONS

1. The creep properties of Al-Cu alloys containing hard particles of  $\text{CuAl}_2$  intermetallic compounds are primarily dependent on the volumetric mean free path of the particles and independent of minor variations in composition (3% Cu to 5% Cu in aluminum alloys) and heat treatment.
2. Dispersions of  $\text{CuAl}_2$  in aluminum result in improving the creep resistance of the alpha solid solution matrix.
3. The creep stress was found to correlate with the creep rate-temperature

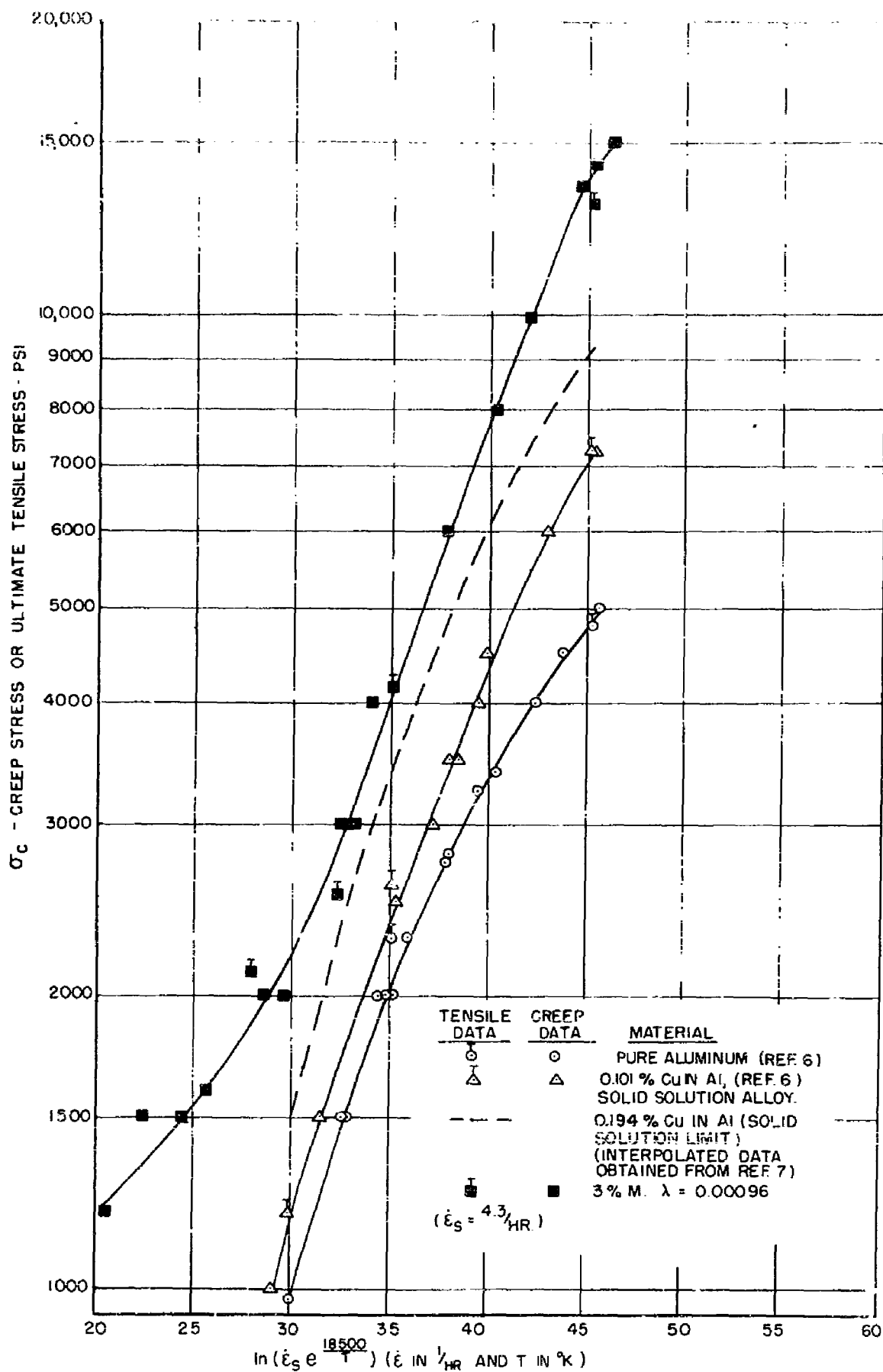


FIG. 6 EFFECT OF DISPERSIONS ON THE  $(\sigma_c - \dot{\epsilon}_s e^{\frac{\Delta H}{RT}})$  CURVE.

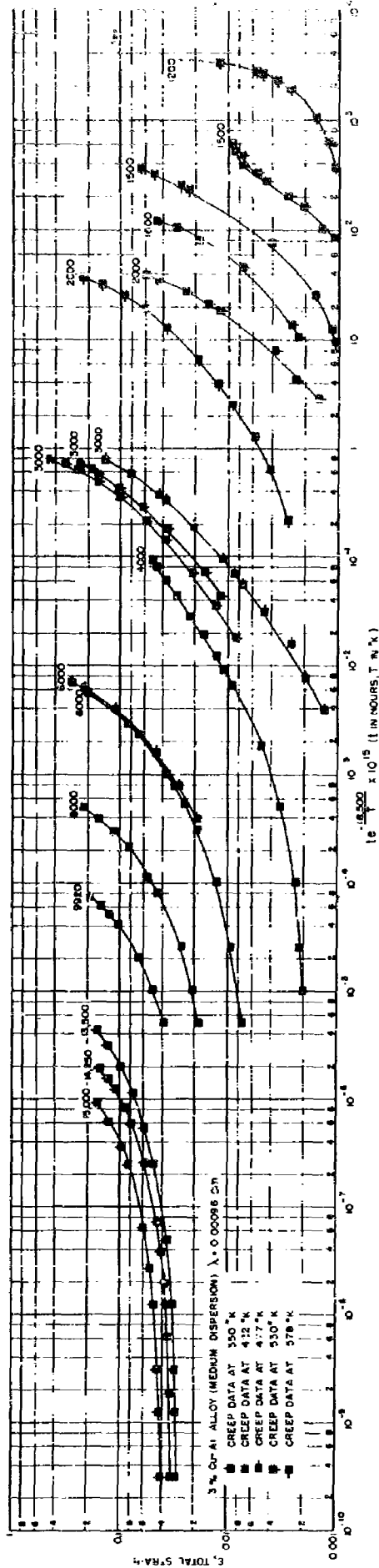


FIG. 7 CORRELATION OF CREEP STRAIN - TIME DATA OF A 3% Cu - Al DISPERSION ALLOY ( $\lambda = 0.00096$  cm.)  
WITH THE TEMPERATURE - COMPENSATED TIME PARAMETER  $t e^{-\Delta H/RT}$

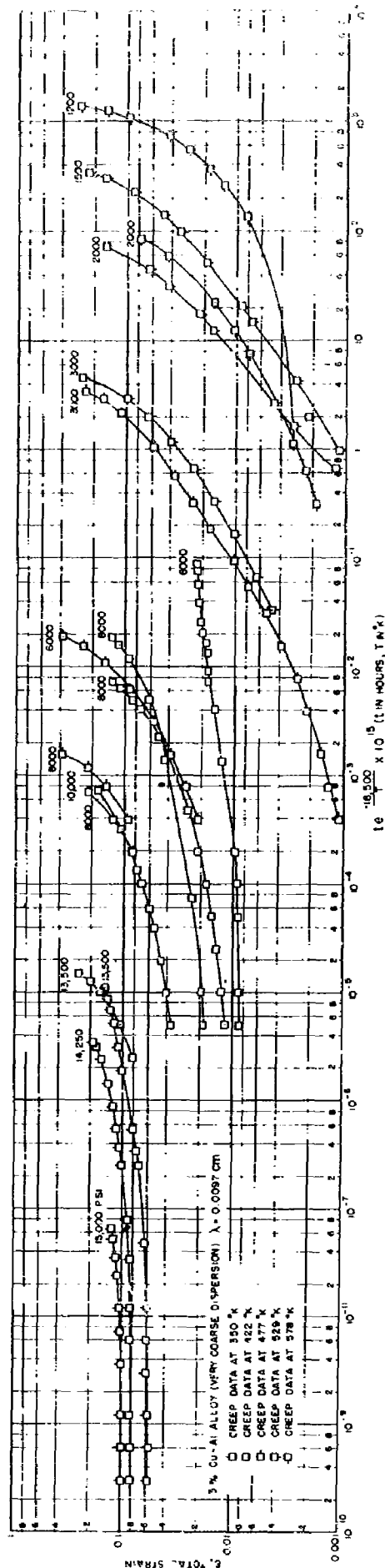


FIG. 8 CORRELATION OF THE CREEP STRAIN - TIME DATA OF A 3% Cu - Al DISPERSION ALLOY ( $\lambda = 0.00097$  cm.)  
WITH THE TEMPERATURE - COMPENSATED TIME PARAMETER  $t e^{-\Delta H/RT}$

parameter  $\dot{\epsilon} = \dot{\epsilon}_s e^{\Delta H/RT}$ . Above  $\ln \dot{\epsilon} = \ln (\dot{\epsilon}_s e^{\Delta H/RT}) = 46.0$  and below  $\ln \dot{\epsilon} = 27.5$  the finer dispersions are superior, whereas the coarser dispersions are superior over the intervening range of  $\dot{\epsilon}$  values. Undoubtedly this factor is associated with the effect of dispersions on recovery rates.  $\Delta H$  was found equal to about 37,000 calories per mole.

4. Constant load creep strains for dispersion alloys appear to be functions of the initial stress and the temperature-compensated time,  $t e^{-\Delta H/RT}$ , analogous to the creep behavior of alpha solid solutions.

#### ACKNOWLEDGMENTS

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In addition the authors wish to thank Dr. C. Dean Starr for his interest in and contribution to this study and to Mr. R. Frenkel thanks are extended for assistance in some of the creep tests.

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APPENDIX



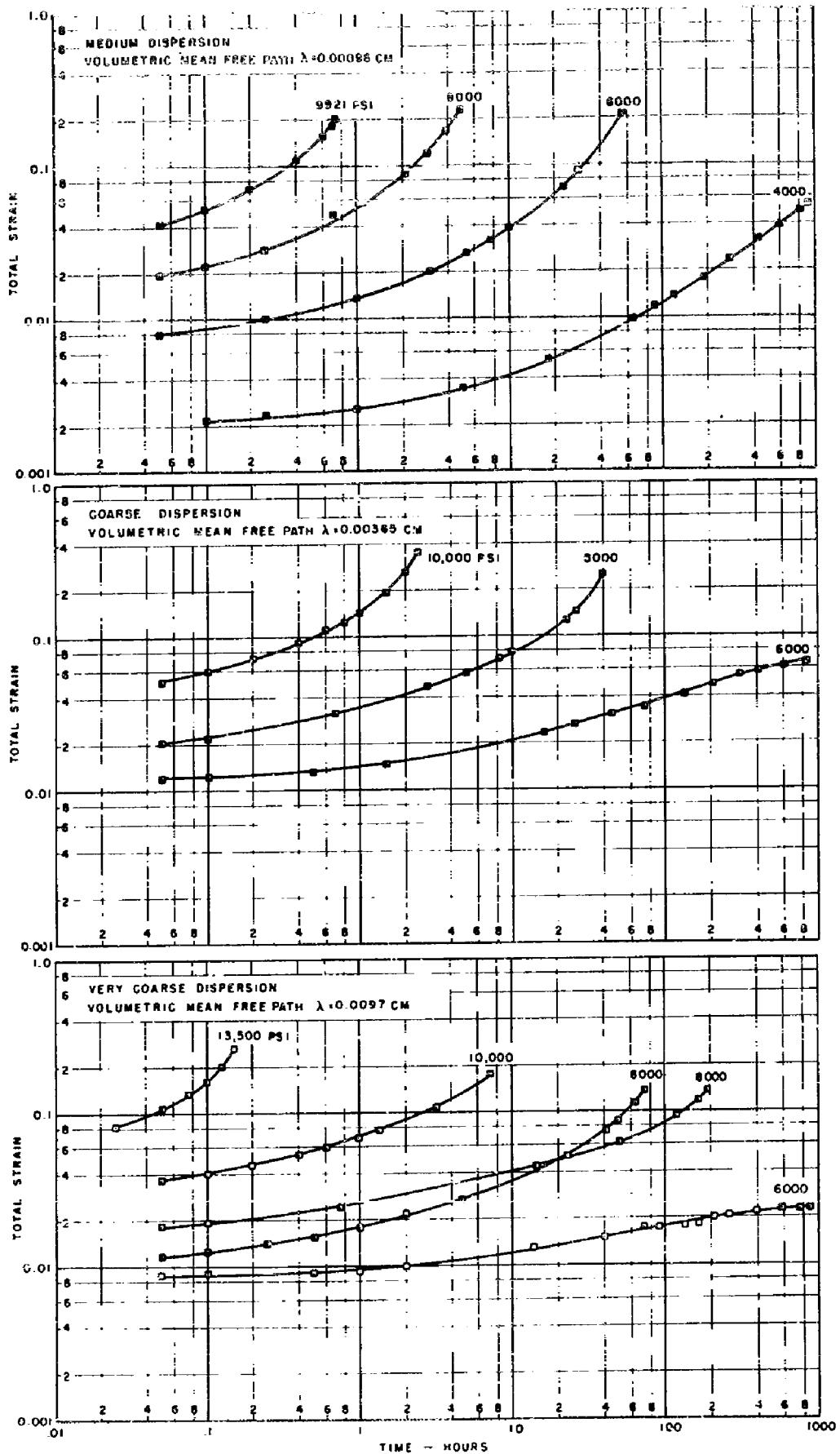


FIG. A1 TOTAL CREEP STRAIN AS A FUNCTION OF TIME FOR VARIOUS DISPERSIONS OF 3% COPPER IN ALUMINUM ALLOY AT 422 °K.

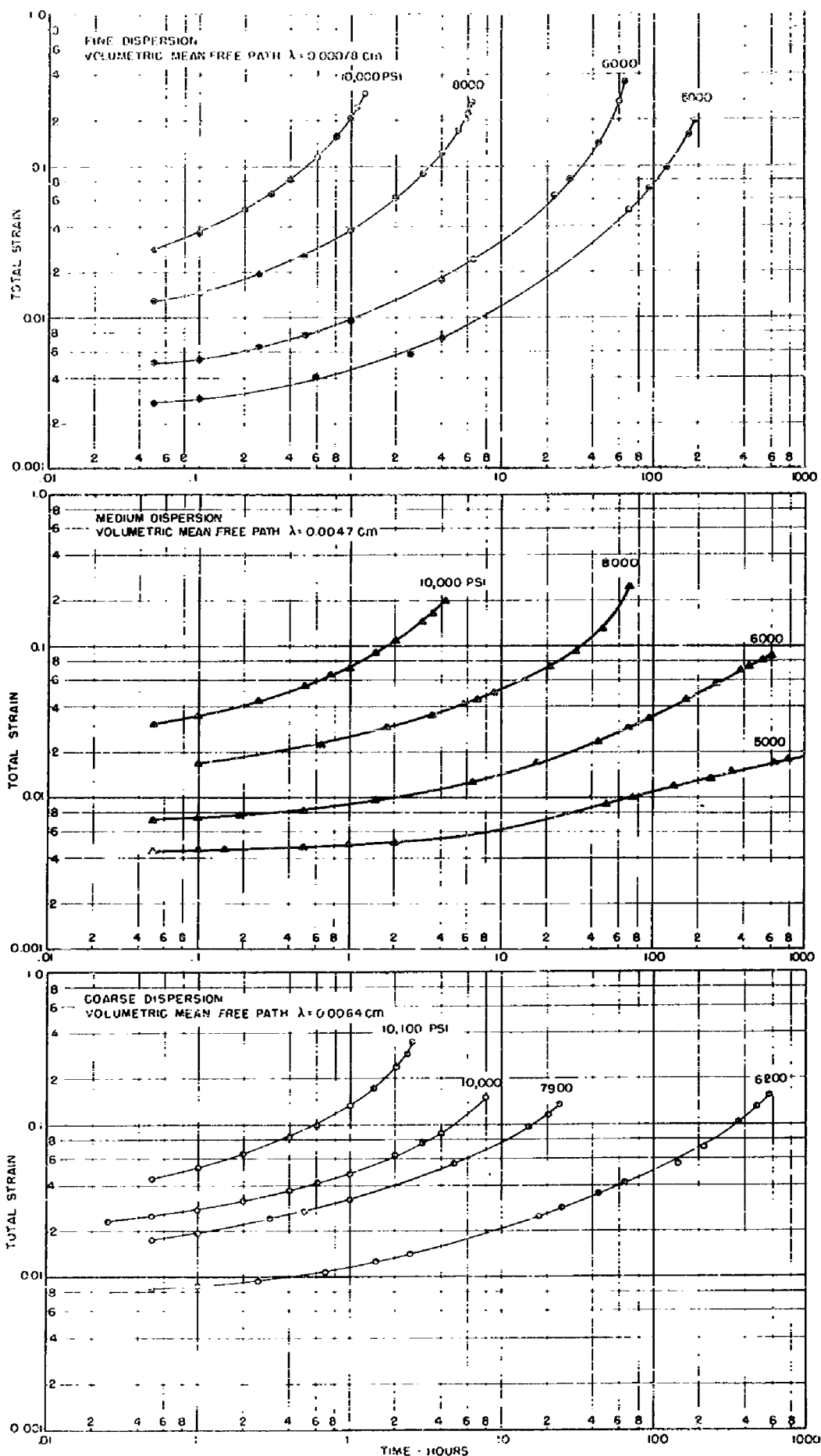


FIG. A 2 TOTAL CREEP STRAIN AS A FUNCTION OF TIME FOR VARIOUS DISPERSIONS OF 4% COPPER IN ALUMINUM ALLOY AT 422°K.

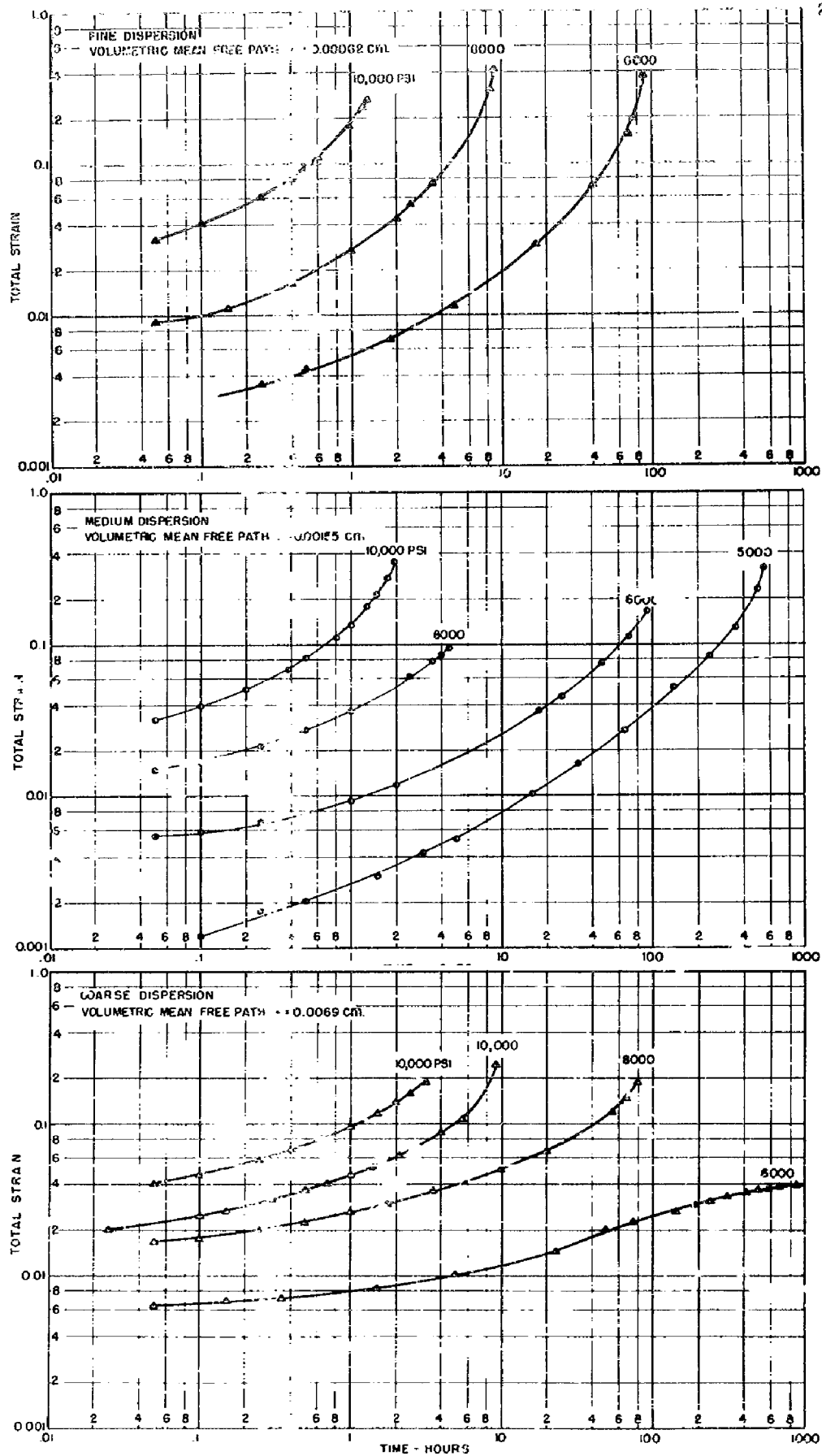


FIG. A3 TOTAL CREEP STRAIN AS A FUNCTION OF TIME FOR VARIOUS DISPERSIONS OF 5% COPPER IN ALUMINUM ALLOY AT 422 °K.

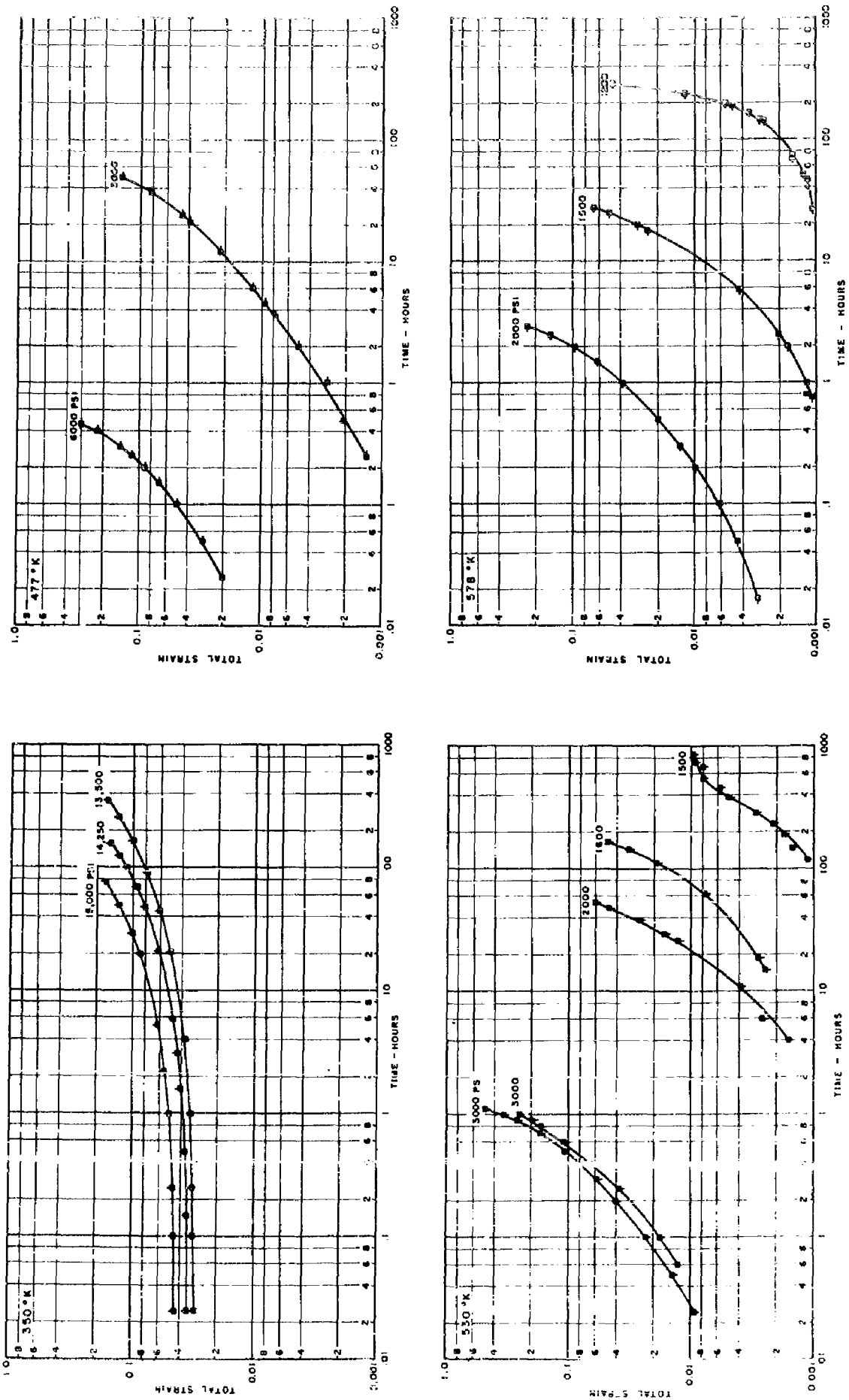


FIG.A4 TOTAL CREEP STRAIN AS A FUNCTION OF TIME FOR THE 3% MEDIUM DISPERSION ALLOY AT VARIOUS TEMPERATURES.

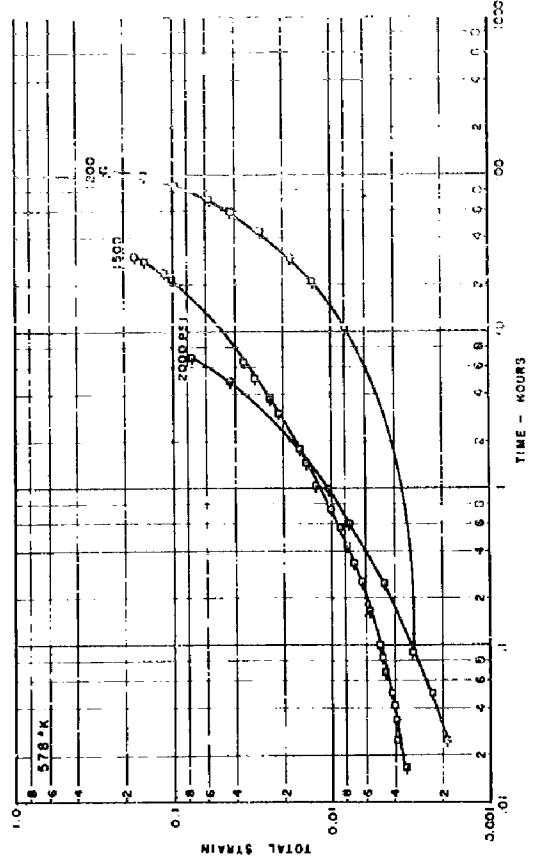
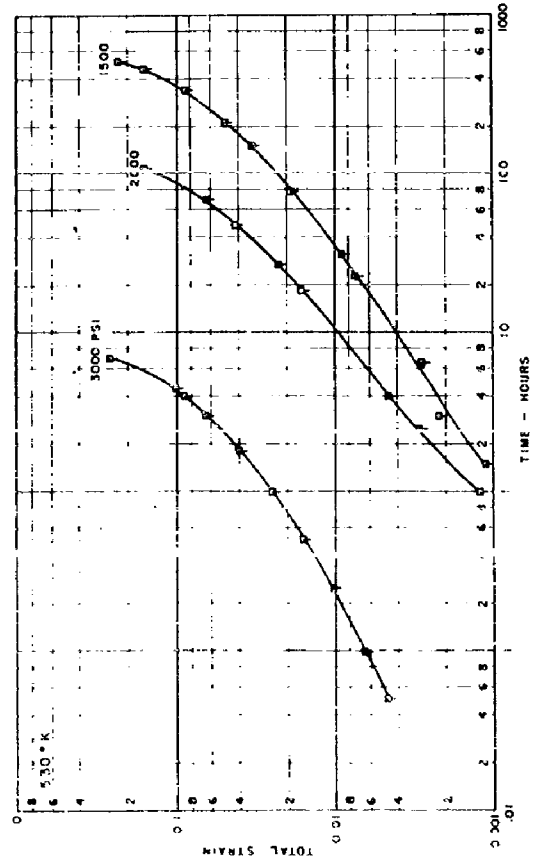
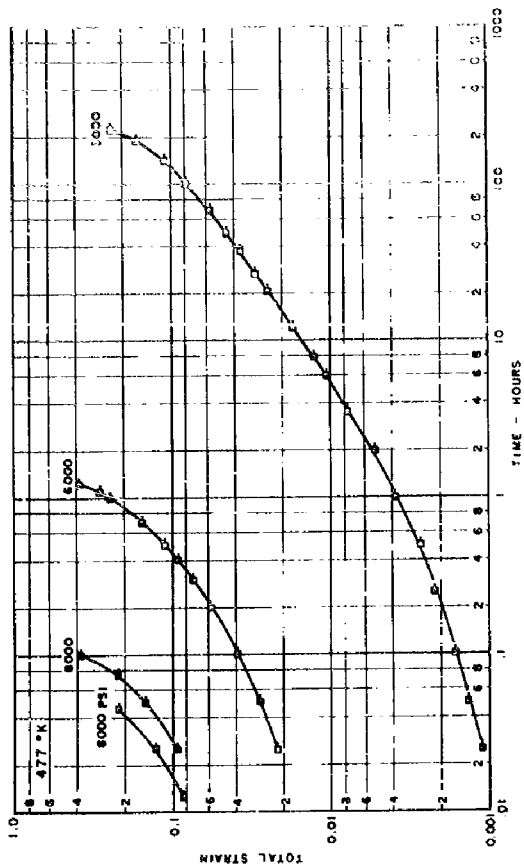
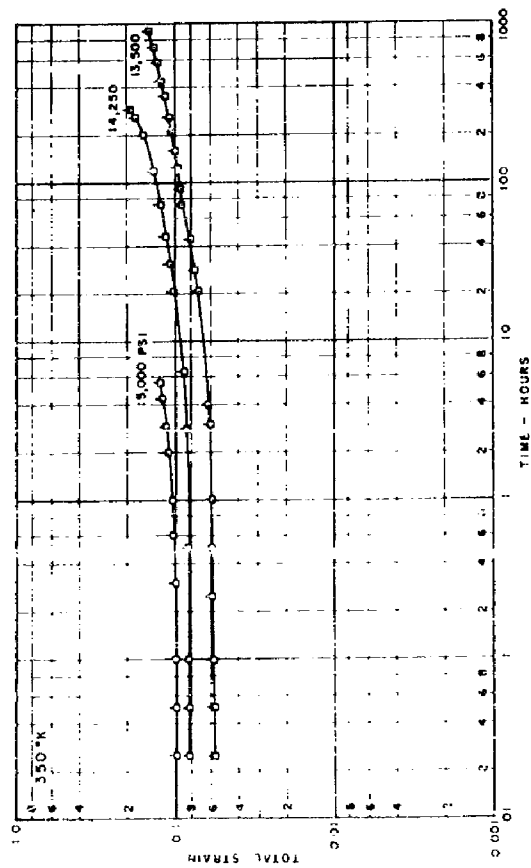


FIG. A 5 TOTAL CREEP STRAIN AS A FUNCTION OF TIME FOR THE 3% VERY COARSE DISPERSION ALLOY AT VARIOUS TEMPERATURES.